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13. ABSTRACT

Two aspects of air-to-ground daylight target acquisition were investigated. Study I examined the task of finding a target displayed on a cockpit-mounted CRT after the pilot had acquired it visually through the cockpit canopy. The effect of three different TV camera fields-of-view on the subject's ability to transition from outside to inside conditions was studied. The second experiment evaluated the differences in acquisition performance elicited by color and monochrome TV display presentations of ground targets. Both tests used 2-D building type target silhouettes which provided a range of contrasts relative to their backgrounds, in terms of brightness and color differences. As in previous study phases, these tests utilized the Martin Marietta Guidance Development Center Simulation facility, including the 40 ft x 40 ft 600:1 scale terrain model, for basic stimulus generation. Results of Study I showed that the experienced pilot subjects detected and then recognized the targets by direct vision before detecting them on the TV monitor. The primary target characteristic influencing detection within each FOV condition appeared to be brightness contrast. The major conclusion was that substantial improvements in integrated TV display subsystem design are required to provide effective direct-viewed-to-on-board display transitioning. Study II results showed that color contrast did not effect displayed target acquisition performance for this type of mission over the range of target/background conditions used. Again, brightness contrast appeared to determine acquisition distance more than any other factor. It is concluded, therefore, that color contrast normally plays a secondary role in airborne target acquisition.

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TARGET ACQUISITION STUDIES:

(1) Transition from Direct to TV Mediated Viewing

(2) Target Acquisition Performance: Color vs Monochrome TV Displays

OR 11,768 JANUARY 1972

Frank D. Fowler
Dr. Daniel B. Jones

Contract No. N00014-67-C-0340
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I. INTRODUCTION

A. BACKGROUND

Two experiments were designed to investigate two aspects of the air-to-ground target acquisition problem. Study I was concerned with the problem of finding a target on a cockpit-mounted TV display after the pilot had acquired it visually through the cockpit canopy. Study II evaluated the differences in acquisition performance elicited by color and monochrome (black and white) display presentations of ground targets.

For the past five years, Martin Marietta Corporation, under the sponsorship of the Office of Naval Research (ONR), has been performing integrated studies of the target acquisition capability of the airborne observer (References 1, 2, 3, 4). Table I summarizes the sample variables that have been tested during this program. The objectives were to obtain parametric baseline data about human target acquisition ability useful in the design of weapon systems and aircraft. To this end, variables have been carefully selected to provide continuity and interpretability to the research. A careful step-by-step progression from simple to complex variables and simple crew tasks was employed. This relatedness was maintained by keeping certain variables constant, by the selection of critical values of other variables, by using experienced pilots as subjects and by using the same experimental designs, techniques, and procedures during the entire program.

The use of on-board displays as integral components of airborne weapon systems is increasing. The utilization of these displays as aids to target acquisition and as the primary means of guiding ordnance to ground targets has added complexity to the pilot's traditional tasks of aircraft operation and gunsight weapons delivery. The quality of typical aircraft TV displays is still too low to enable the airman under usual daylight conditions to improve his direct viewing capability. Additionally, where there is only a single crewman (the pilot), he is forced to acquire the target visually while performing his normal duties of flying the plane.

When the pilot acquires the target by looking out his canopy, he must then acquire the target on his display if he is to use that display for ordnance delivery. This transition from direct viewing to display mediated viewing has not received much study to date. What are the limitations in terms of time to reacquire the target on the display? Without considering the increased work load demands on the pilot, how long does

TABLE I

Summary Comparison of the Primary Variables Tested in the ONR Target Acquisition Study Phases

Phase	Viewing Medium	Targets Type and Size	Viewing Condition	Target/Background Contrasts	Fields-of-View (Horizontal)	Objectives
I OR 9656	TV	2-D Simple Building-type Briefed and Unbriefed Target Shape: house, right and left sheds offset from center of target area Target Size: 62.5 X 31.25 feet (Simulated)	Dynamic	5, 10, 15, 20, 25, and 35 percent	4.85, 7.27, 9.78, and 14.48 degrees	Effects of Fixed TV Fields-of-View
II OR 10,399	Direct	2-D Simple Building-type House, right and left shed 22.5 X 45 feet (Simulated) Unbriefed Search (cluttered) and no Search (threshold) recognition tests Three target offset levels	Static and Dynamic	5, 10, 15, 20, 25, 35, and 50 percent	NA	Threshold and Optimum Target Acquisition for Directly Viewed Targets
III OR 10,689	TV	2-D Briefed Building-type House, right and left sheds Open and Cluttered Background Target always in center of monitor Target Size: 31.25 X 62.5 feet (Simulated)	Static and Dynamic	10, 25, 35, and 50 percent	7.3 and 14.5 degrees	Threshold and Optimum Target Acquisition for TV Displayed Targets
IV OR 11,091	(1) Direct and TV	2-D and 3-D Vehicular and building-type targets, briefed	Dynamic	15, 20, 25, 30, 35, and 40 percent	5 to 35 degrees Variable due to use of Zoom Closure	Compare Acquisition of 2-D and 3-D Targets
	(2) TV	2-D Building-type targets, briefed		Contrast varied with gamma setting	5 to 35 degrees Variable (Zoom Closure)	Evaluate effects of changes in TV Gamma
V OR 11,768	(1) Direct-to-TV Transition	2-D Building-type targets, briefed		8 to 62 percent	4.8, 9.6, 14.5 degrees	Direct to TV Transition Performance
	(2) TV		Dynamic	21 to 85 percent	15 degrees	Effects of Color versus Black and White TV on Acquisition

Note: All TV studies (except V(2), which used a 525 line color camera and 12-inch color monitor) used a 525 line TV system with an 8-inch monitor on a 600:1 scale terrain model. Operator viewing distances used were either 18 or 20 inches. Illumination levels at the model surface were approximately 250 to 400 footcandles. The flight profile used was a straight-in approach at a constant altitude of 3,000 feet at 350 knots. A target offset from the center of the display was used where noted to ensure search of the display or of the terrain model. Experienced, former military pilots were used in all studies. Target/background contrast in the TV studies were measured on the monitor.

it take a pilot to accomplish this transition? The objective, then of this first phase of the present study was to examine this interface. Without compounding the problem with pilot workload problems, what are the typical ranges and time requirements for this direct view-to-TV-display transition under laboratory conditions? Once these optimum target acquisition conditions are established and added to the data, the problems of secondary task interference, workload priorities, and other operating problems can be addressed.

The second phase of this study was exploratory in nature and was designed to quantitatively provide initial answers to the question of the efficacy of color versus black and white TV display presentations on target acquisition performance. Statements unsupported by any substantial amount of empirical data have intimated that color presentations require only one-half the resolution of monochrome systems to elicit equivalent performance. There was also the potential psychological impact of a realistic color display imparting more basic information to the observer. The increasing availability and decreasing cost of color TV systems suggested that empirical data should be obtained and evaluated.

B. OBJECTIVES AND APPROACH

1. STUDY I - Transition from Direct to TV Mediated Viewing.

The objective was to determine the ability of a trained pilot-observer to "transition" from viewing a target directly to reacquiring that target on a cockpit-mounted TV monitor.

The three-dimensional terrain model of the Martin Marietta Corporation's Guidance Development Center (GDC) was used to present realistic target and terrain information to pilot-observers who were stationed in a cockpit mockup overlooking the model. This approach used three different TV camera fields-of-view which were used to evaluate this parameter. Several target/surround color combinations and contrast levels were employed. To provide continuity to the program targets, environmental, and flight conditions were similar to previous tests.

2. STUDY II - Target Acquisition Performance: Color Versus Monochrome TV Displays.

The objective was to determine whether the use of a color TV system to mediate airborne target acquisition is superior to that of a black and white system.

Color and monochrome videotape recordings of simulated flights on the GDC terrain model were made. Several target/surround color combinations and contrast levels were selected to present a range of stimulus material to the experienced pilot subjects. Again the targets and environmental and flight conditions were similar to previous tests in the series.

II. EXPERIMENTAL METHODS

A. STUDY I. TRANSITION FROM DIRECT TO TV MEDIATED VIEWING

1. Test Procedures

This study was designed to measure the pilot's ability to make a transition to an on-board display and reacquire a target he had acquired visually. Three fields-of-view were selected to evaluate this effect on transitioning performance.

The subject was seated on the observer platform overlooking the three-dimensional terrain model. A TV monitor was mounted in the cockpit (platform) at a viewing distance and angle typical of a single seat aircraft installation. The subject was shown a photograph of the terrain model with the one-half mile square target area outlined. After he had oriented himself to the terrain and the prebriefed target area, the trial was started. The terrain model closed range on the subject's fixed position, which simulated flight towards the target area. The subject visually searched the target area, acquired the target, then shifted his gaze to the TV monitor and attempted to acquire the target on the display. The subject pressed a button to denote the several acquisition decisions occurring during each run. He simultaneously reported detection and recognition verbally to the test monitor. At the end of each trial the cockpit window and the display were covered while a new target and target area were selected.

Each subject was instructed that the objective was to detect and recognize the target in the shortest time possible. This could be accomplished by acquiring the target, i.e., detecting and recognizing the target directly and then detecting it on the monitor, or by detecting it directly and then detecting and recognizing it on the monitor.

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2. Experimental Design

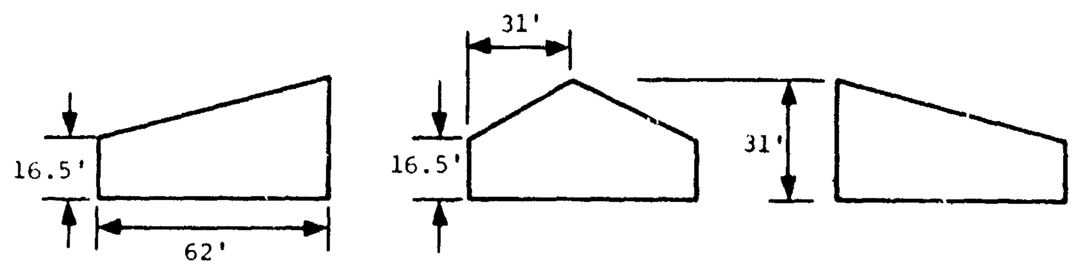
a. Independent Variables

1) Fields-of-view*

Three fields-of-view were selected: 4.8, 9.6 and 14.5 degrees. These FOVs corresponded to those used in previous tests in this series.

2) Target Areas

The targets consisted of the two-dimensional building silhouettes used in the previous tests in this series (refer to the sketch). Because the targets themselves elicited similar responses, their shapes were not considered a significant factor and each type of target was used interchangeably. The targets and selected areas were therefore considered as a single entity. Two other characteristics of the target and background combinations, namely, brightness contrast and target and background colors, were considered to be important variables. Because the subjects would be viewing a natural scene in color in the direct view mode and then switching to a monochrome display, the effect of these two variables was of concern. Eight target/background combinations were selected and the brightness levels photometered (from which contrasts were computed). Both directly photometered and display photometered values were obtained, and are listed in Table II, along with areas and associated color schemes. A wide range of contrast was selected, and two of the eight areas contained targets which were color mismatched with their backgrounds. Due to nonlinearities in the TV system, displayed contrasts were found to be consistently lower than their directly photometered counterparts. However, most contrast values were high, i.e., between the 20 and 60 percent level, where the effect of changing contrast on performance tends to be relatively insignificant. Therefore, this difference in direct and displayed contrast values was not considered to be a major factor. Two area/target combinations were deliberately mismatched: 14/17 and 17/2. (The area numbers refer to particular areas on the terrain model, e.g., 18. The designation for 14/17 means that a target with the same color (or spectral characteristics) as that of area 14 was placed on area 17).



* Refers to horizontal FOV size - a standard 3 x 4 scan format being used.

TABLE II

Target/Area Characteristics for Study I

Area	Brightness Contrast (Percent)		Target/Area Color	Target
	DV	TV		
17/2	57	52	Dark Green/Tan	RS
14	41	31	Tan	H
18	54	32	Light Green	RS
20	52	27	Light Green	LS
34	34	20	Green	H
13	50	25	Brown	LS
14/17	10	6	Tan/Green	H
4	37	22	Light Brown	LS

3. Response

The subjects responded three times during each trial. Responses were made following: 1) search and detection of the target while viewing the terrain from the window of the cockpit mockup; 2) detection of the target on the TV display; and 3) recognition of the target either by direct view or on the display. Because it was not known whether the pilots would be able to detect and recognize the targets on the TV display, the basic statistical layout (analysis of variance) was determined after the test was completed. It was found that the subjects were able to detect and recognize the targets directly prior to detection on the display. This resulted in three times as many direct vision detections and recognitions as there were TV detections since the TV detections were divided among the three FOVs. These were pooled for analysis as a complete factorial as outlined in the following section.

4. Target Offset

Targets were offset from the center of the prebriefed target area to ensure that a search task was created.

5. Dependent Variables

The primary dependent variable was slant range to the target which was measured for each subject response. Elapsed time between detection of the target directly and detection on the display was also measured. The number of missed detections was analyzed to obtain the probability of detection for each FOV and direct view condition.

6. Experimental Parameters

The experiment was conducted under simulated flight conditions using the Guidance Development Center's 600:1 scale three-dimensional terrain model. The following conditions were standard for each trial run:

1 Altitude: An altitude of 3000 feet was simulated

2 Airspeed: 350 knots simulated

3 Target locations and flight path:

The targets were located in prebriefed, square target areas, one-half mile on a side. The flight path was held constant and extended to the center of the target area while the targets were displaced from this flight line. The TV camera tracked to the center of the target area and always presented this prebriefed area centered on the TV monitor.

7. Experimental Design and Statistical Analysis Summary

The basic experimental design consisted of two responses: detection and recognition; three FOVs: 4.8, 9.6 and 14.5 degrees, and eight target areas. For the basic analysis a two-way layout was run with eight areas and five response categories. The response categories were: detection-direct view, recognition-direct view, and detection-TV for each FOV. Where significance was indicated, a Scheffé test was used at multiple data points and a t test was used where only two data points existed.

8. Subjects

Six experienced civilian or ex-military pilots were selected for the tests.

B. STUDY II. TARGET ACQUISITION PERFORMANCE: COLOR VERSUS MONOCHROME TV DISPLAYS

1. Test Procedures

This study was designed to compare target acquisition performance between color and black and white displays. Both color and monochrome TV video recordings were made on each target area. The areas were arranged in a selected sequence which consisted of 28 trials. Fourteen target areas were selected on the basis of color matching, i.e., both target and background having the same basic color and differing only in brightness contrast,and color mismatching. Four target/backgound combinations were mismatched while ten were matched. The matched areas were selected to determine whether the basic color representation would enhance acquisition. For example, where targets and their surrounds are closely matched by camouflage paint, the TV image would be a monochromatic display of that particular color. Thus, this particular

investigation is concerned with whether a color transmission of that scene would elicit different performance than a black and white display. The second area of investigation relates to acquisition performance differences between color and monochrome displays of mismatched target/background combinations.

Subjects were seated in front of a color TV monitor and were instructed to detect and recognize the targets which would appear in the central region of the display. The subjects responded verbally when they detected and recognized the targets. Slant ranges were recorded orally onto the soundtrack of the tape. When the subjects responded, the test monitor recorded the slant range.

Because this was an exploratory study, a cross-selection of target and background areas and color combinations was employed. These selected areas are listed in Table III along with their displayed contrast values (monochrome and color modes) and target/background colors. While it was desired to obtain some measure of color contrast, there was no instrument available capable of making small area measurements of this type.

2. Experimental Design

The experiment was arranged into a 2 x 2 x 14 complete factorial analysis of variance with 12 experienced pilot subjects used as replicates.

Independent Variables	Number	Values
Mode	2	Color and monochrome
Response	2	Detection and Recognition
Target Area	14	See Table III

Experimental parameters were: Altitude-3000 feet; Airspeed-350 knots.

a. Mode

All target/background combinations were presented in color, and black and white. Trials were selectively arranged in an irregular presentation of Modes as well as target areas.

b. Response

Detection and recognition of the target for each trial was required.

c. Target Area

The 14 areas were selected to present a wide range of colors and target/background color combinations.

TABLE III.

Study II: Color versus Monochrome Test. Target/Background Characteristics

Target Area	Basic Color	Brightness Contrast - Displayed (percent)		
		Color	B&W	Average
11	Lt. Grn	65	65	65
2	Tan	42	40	41
18	Lt. Grn	49	42	46
20	Lt. Brn	53	55	54
4	Grn	40	39	40
14	Grey	36	38	37
15	Grn	42	33	37
13	Lt. Grn	43	43	43
17	Dk Grn	45	46	46
34	Grn	37	39	38
20/11	Lt. Brn/Lt. Grn	69	68	68
17/2	Dk Grn/Tan	86	83	84
18/14	Lt. Grn/Grey	28	33	30
14/17	Grey/Dk Grn	23	20	22

III. DISCUSSION OF RESULTS

A. SUMMARY

1. STUDY I - Transition from Direct to TV Mediated Viewing

Results showed that the pilots consistently detected and then recognized the targets when viewing through the simulated windscreen before they detected the TV displayed target images. Simulated detection ranges were as great as 61,000 feet for direct viewing compared to less than 19,000 feet for TV detection using the wide 14.5 degree FOV. Mean times for locating and detecting the target on the monitor after directly acquiring the target ranged from 19 seconds with the 4.8 degree FOV to 32 seconds with the 14.5 degree FOV. The direct viewing task produced greater subject variability than did the TV mediated task. The major target characteristic influencing detection appeared to be brightness contrast. Color (in the direct vision test) and offset from the flight line did not appear to affect performance. The narrow 4.8 degree FOV provided greater detection ranges than the wide FOVs; however, the detection probabilities were significantly lower in the narrow FOV case. It can be expected that these performance levels will be somewhat degraded when normal pilot/crewman task loading is injected into the mission.

2. STUDY II - Target Acquisition Performance: Color Versus Black and White TV Displays

There was no difference between target acquisition performance using color and monochrome TV displays. Also, within the color display mode, target/area combinations that were mismatched elicited performance similar to those with targets that were color-matched to their surrounds. Brightness contrast appeared to overshadow the effects of color for this study, which employed only high contrast target areas. While there was a statistically significant difference between detection and recognition performance, only four areas out of 14 evidenced this difference in performance. For these four areas, the targets were in the open and the areas were easy to locate after the subjects were prebriefed. Detection and recognition occurred almost concurrently for the other areas because of the difficulties in locating the target area and, once locating it, separating the target from competing objects. In the latter cases, the recognition threshold was reached by the time the detection occurred.

B. STUDY I - TRANSITION FROM DIRECT TO TV MEDIATED VIEWING

1. Responses

The dependent variables (slant range at detection and recognition under direct viewing, and corresponding detection ranges for the three FOV conditions with TV mediated viewing) varied from a maximum value of over 60,000 feet in the directly viewed case to 19,000 feet for detection at the 14.5 degree FOV. It was hypothesized that the subjects would detect the targets directly, then detect them on the TV display and then recognize them on TV. However, the pilots were able to detect and recognize the targets directly before detecting them on the display. Recognition occurred on an average of 8.2 seconds after detection.

Detection times under the three different FOVs varied from an average of 19 seconds (after detection by direct viewing) for the 4.8 degree FOV to 29 seconds for the 9.6 degree FOV to 32 seconds for the 14.5 degree FOV. Minimum and maximum detection times are shown in Table IV. These ranged from 3 to 30 seconds for the 4.8 degree to 10 to 44 seconds for the 14.5 degree FOVs. This wide variation was probably due to an interaction of several factors, including contrast of the target to the background, target offset, and search strategies. A graphical presentation of the differences in the display detection times after direct viewing detection is shown in Figure 1. Target areas having similar performance levels are combined to form two groups as explained below. The 4.8 degree FOV performance for Group A was significantly different from the 9.6 degree and 14.5 degree FOVs. For Group B the 4.8 degree FOV was significantly different from the 14.5 degree FOV.

TABLE IV

Time Required to Transition to Display After Visual Detection

Area	Field-of-View 4.8 Degrees	9.6 Degrees	14.5 Degrees
	(sec)	(sec)	(sec)
17/2	25.5	41	42
14	15	32	32
18	12	29	38
14/17	30	38	44
4	17	34	34
13	17	22	27
34	30	27	27
20	3	10	10
Average	19	29	32

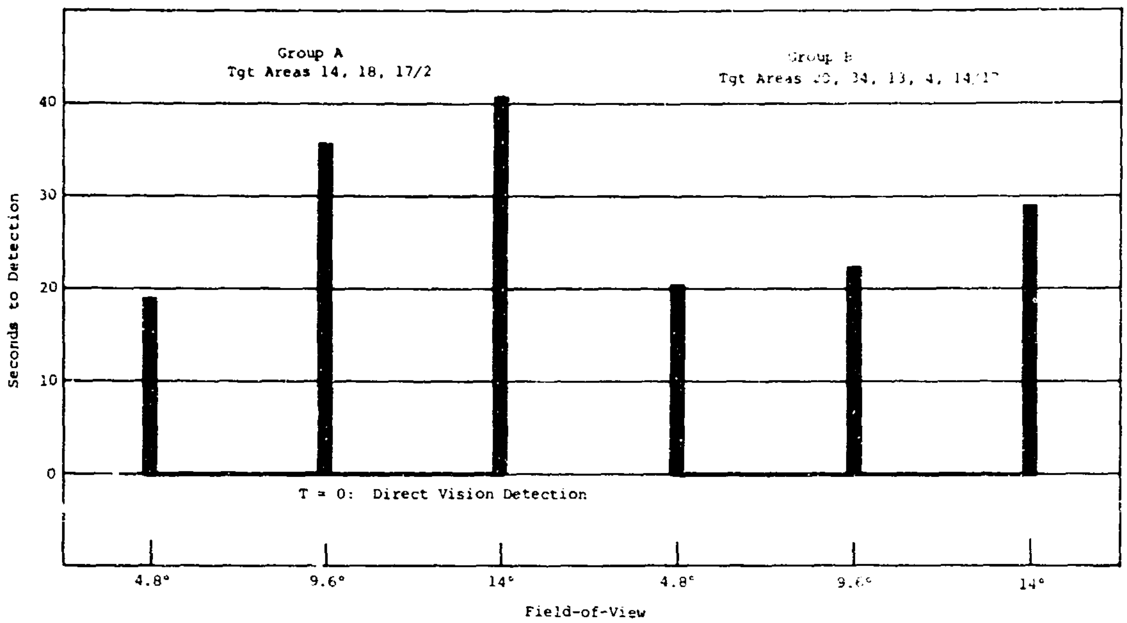


Figure 1. Target Acquisition Transitioning Time Measured as Time to TV Mediated Detection.

There was a greater degree of variability in the direct viewing mode than was evident in the TV mode. Even though the pilots were briefed on a one-half mile square area, the problems of orientation and unfamiliarity with the whole terrain model contributed to this direct viewing variability. Once the target was visually detected, the search area was confined to the displayed area. This is believed to be the major reason for the smaller subject variability in the TV mediated case. A multiple t test performed on the data at each FOV and directly viewed data point reflected this variability. The detection performance fell into two distinct groups for the three FOV conditions as shown in Figure 2. The first group (designated Group A for convenience) consisted of areas 17/2, 14 and 18. Group B contained areas 20, 34, 13, 14/17 and 4. For a clearer picture, these two groups are averaged and presented in Figure 3. The reason for this grouping is discussed in the following paragraph. The primary reason for the differences in detection performance is felt to be the brightness contrast factor.

2. Target Areas

Figure 2 shows the response levels (averaged across subjects) for each viewing condition. The brackets denote non-significance as determined by the multiple t test. The logic in grouping areas 17/2, 14, 18 and 20, 34, 13, 4 and 14/17 can be seen in Figure 2 where significance as determined by the multiple t test is shown by absence of bracketing.

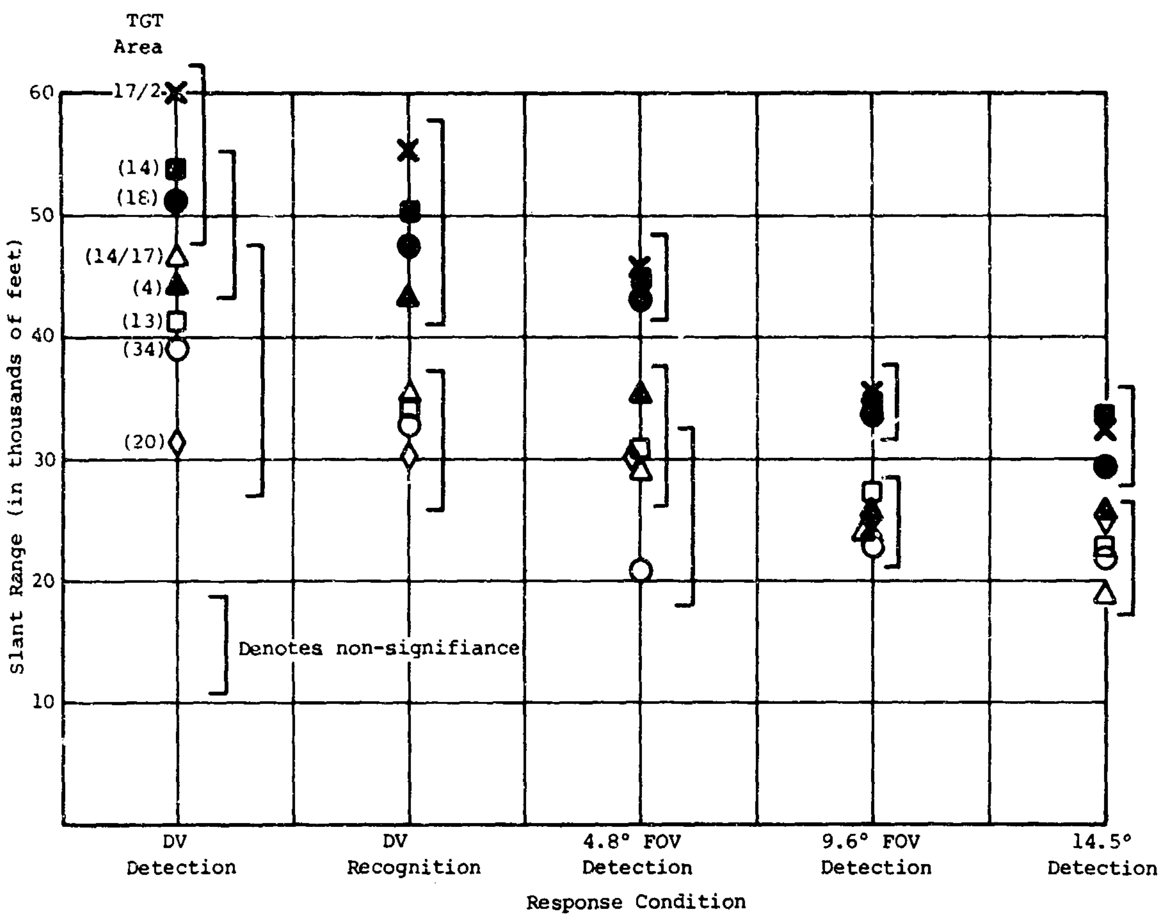


Figure 2. Target Acquisition Transitioning Performance as a Function of Area for All Response Conditions.

Review of the basic data indicates an interesting interaction in the direct vision case between target/background (brightness) contrast and target/background color mismatch. Two areas (17/2 and 14/17) contained color mismatches. Area 17/2 had a directly photometered contrast (DV) of 57 percent, and subject performance was not significantly different from areas 14 and 18, which had similar contrast values without target/ background color mismatches. On the other hand, area 14/17 had a contrast of 10 percent, however, it elicited similar performance to areas having average contrasts of 45 percent. This apparently was caused by the color mismatch in area 14/17 becoming the dominant effect. In the TV mediated case, this particular interaction was not experienced, since only the image brightness components were displayed and photometered to compute TV contrast values.

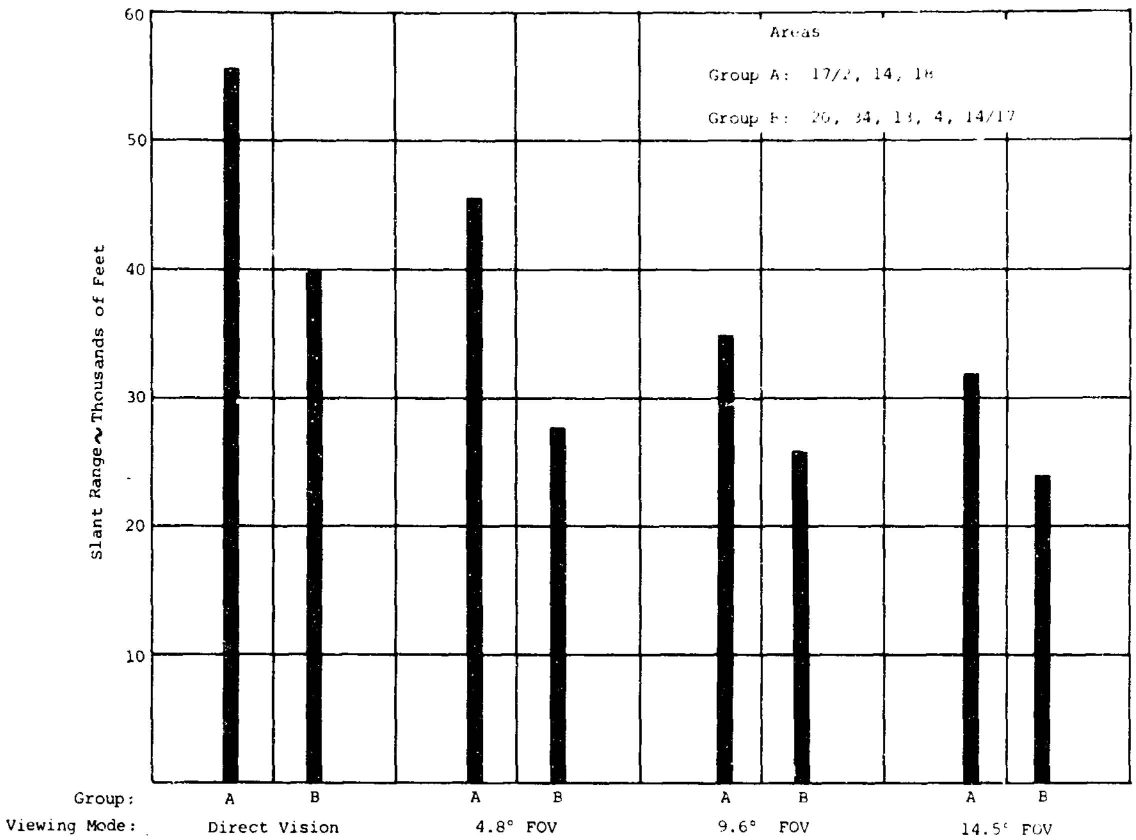


Figure 3. Comparison of Average Detection Ranges Between Groups A and B.

Table V lists the TV and DV contrast values for each target area. As noted in the Methods section, dissimilar DV and TV contrast levels were obtained because of the nonlinear transfer characteristic of the TV system. Figure 4 shows performance on each area as a function of slant range.

TABLE V

Comparison of Direct and Displayed Target-to-Background Brightness Contrast Values for Groups A and B

Group A			Group B		
Area	Contrast		Area	Contrast	
	DV	TV		DV	TV
17/2	57%	52%	20	52	27
14	41	31	34	34	20
18	54	32	13	50	25
Average	51	38	14/17	10	6
			4	37	22
			Average	37	20

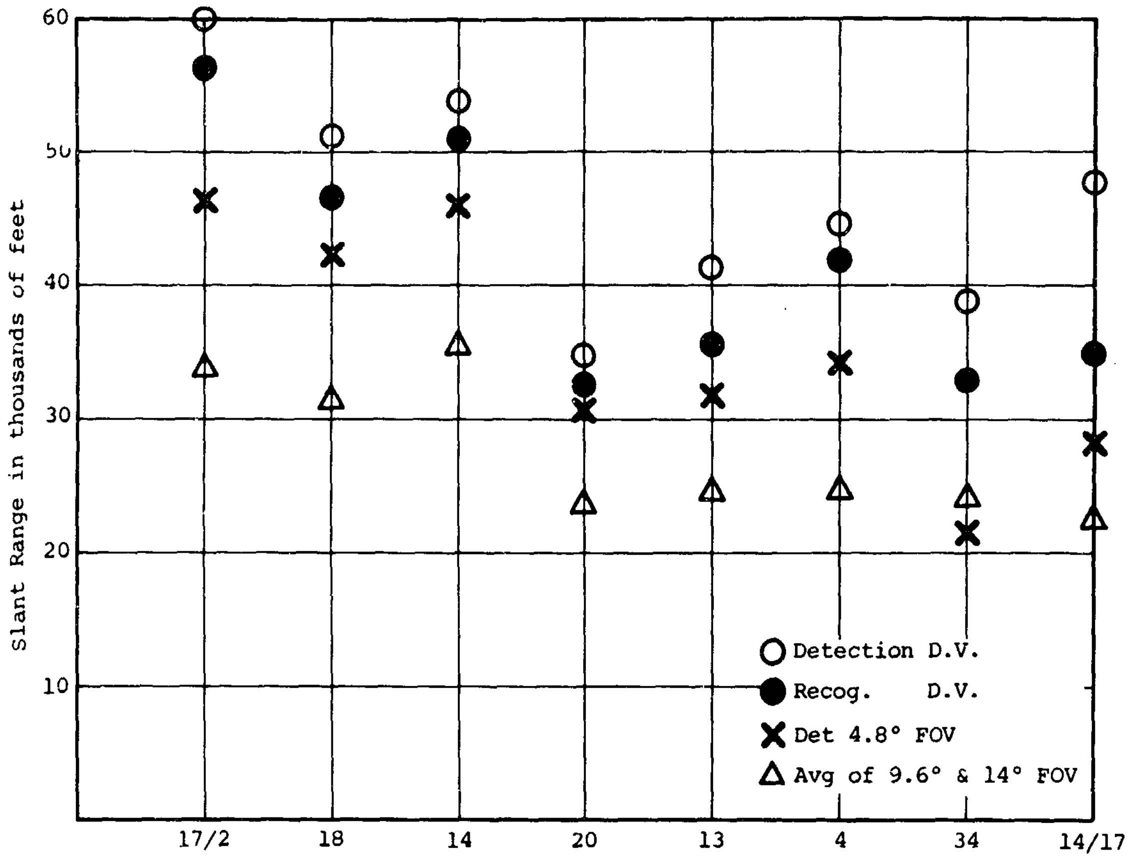


Figure 4. Detection and Recognition Performance as a Function of Viewing Mode.

3. Fields-of-View

The analysis of variance summary (Table VI) indicated that the response variable was significant at the 0.01 level. Further analysis with the t test showed that the 4.8 degree FOV was significantly different from both the 9.6 and the 14.5 degree FOVs. These latter FOVs were not significant from each other. It is felt that this effect can be accounted for by considering the relative change in FOVs. There was a 100 percent increase between the smallest and the middle FOV, and approximately a 50 percent increase between the middle and largest FOV.

Because each of the targets was initially within the displayed area, the higher image magnification achieved with the smaller FOV resulted in detection at greater ranges. Analysis of the number of undetected targets, however, indicated that, while targets could be detected at longer slant ranges, the number of missed or wrong detections was higher. Table VII lists the probabilities of both direct visual and TV detection based on the percentage correct. Again, there was no significant difference between the two wider FOVs, but there was between those and the 4.8 degree FOV.

TABLE VI

Analysis of Variance Summary for Transitioning From Direct Vision to TV Displays

Source	DF	SS	MS	F	Signif.
Area	7	10851.30	1550.18	30.3	0.01
Response	4	13091.48	3272.87	63.8	0.01
AxR	28	2030.88	72.53	1.41	NS
Residual	200	10272.02	51.36		
Total	239	308574.9			

TABLE VII

Direct Visual and TV Detection Probabilities

Probability of Detection (P_d)

P_d(DV)	0.93
P_d(4.8°)	0.67
P_d(9.6°)	0.83
P_d(14.5°)	0.85

The smaller P_d for the 4.8 degree FOV is at variance with results obtained on the first test in this series (Reference 1). In that instance, the problem was to view the target solely on the TV monitor. It was concluded in that study that the available exposure time, i.e., the time between the target reaching detection threshold and the time available for viewing before the target passed out of the FOV, was less with the larger FOVs. The subjects under those conditions either saw the target quickly or not at all. In this study the experimental situation is somewhat different and the subjects' strategy appeared to be different. Here the subjects attempted to correlate what they were seeing thru the cockpit window with images on the display. Because of the greater image magnification provided by the 4.8 degree lens, candidate targets were above detection threshold sooner. Instead of waiting and maximizing the probability of a correct detection, the subjects tended to guess before they took the time to completely orient themselves to the displayed terrain. This tendency to guess could be eliminated thru training and would be further reduced on an actual mission if the importance of correct detection were stressed.

In addition, once recognition was made directly, the TV detection task was somewhat different from the tasks examined in previous studies in this series. Since the subjects then knew the basic shape and location of the target after recognition, the TV detection task presumably was aided by this added knowledge. In previous tests where the subjects were viewing only the TV display (Reference 1) they had no similar prior knowledge. Theoretically, the TV detection on this test should have been enhanced. This was borne out by the fact that average detection ranges were slightly higher for the present test than they were for the earlier "pure TV" tests (Reference 1).

Differences (i.e., degraded performance) can also be expected when normal task loading is introduced into the simulation. In this test, the pilot's only duty was to detect the target and transition to his on-board monitor. In fully simulated tests (or an actual mission) the workload of the pilot would tend to degrade performance.

For systems which are boresighted to the aircraft gunsight, or are slaved to a helmet sight so that the directly viewed LOS is always in the central portion of the diplay, a narrower FOV could be used to increase detection range. Under these conditions, zoom or stepping lenses could increase both TV detection and recognition performance.

C. STUDY II - TARGET ACQUISITION PERFORMANCE: COLOR VERSUS MONOCHROME TV DISPLAYS

The analysis of variance (Table VIII) indicated that the mode effect, i.e., color versus black and white was not significant. Target areas and the detection and recognition response variables were significant at the 0.01 level. Two interactions, Response by Area and Area by Mode, were also significant at the 0.01 level. Using the t test or Scheffé test (where applicable) the significant variables and interactions were further analyzed and are dicussed in detail in the following sections.

1. Response.

The response main effect (detection and recognition) was significant at the 0.01 level. There was a significant interaction between the response and area parameters which accounted for a small amount of variance. This is shown in Figure 5. A t test performed at each area indicated that there was a difference in detection and recognition ranges for only four areas (14, 15, 18/14 and 17/2). With all other areas the subjects detected and recognized the targets at approximately the same instant. This almost simultaneous detection and recognition is characteristic of target acquisition where a search task is involved (Reference 1) and the pilot must discriminate among several candidate targets. Areas 13, 34, 17, 18, and 14/17 could be considered as having other objects in proximity which would create this effect. The other four targets (14, 15, 18/14 and 17/2) were situated in fields that were relatively easy to locate and few natural terrain features or other manmade objects were there to compete for the pilot's attention.

TABLE VIII

Analysis of Variance Summary for Study II:
Color versus Monochrome Target Acquisition

Source	DF	SS	MS	F	Signif.
Mode (M)	1	2.0	2.0	<1.0	NS
Response (R)	1	1295.4	1295.4	128.5	0.01
Area (A)	13	6314.9	485.8	48.3	0.01
RxA	13	914.7	70.4	6.9	0.01
RxM	1	23.2	23.2	2.3	NS
AxM	13	2181.8	167.8	16.6	0.01
RxAxM	13	159.2	12.2	1.2	NS
Residual	616	6240.7	10.1		
Total	671	17132.1			

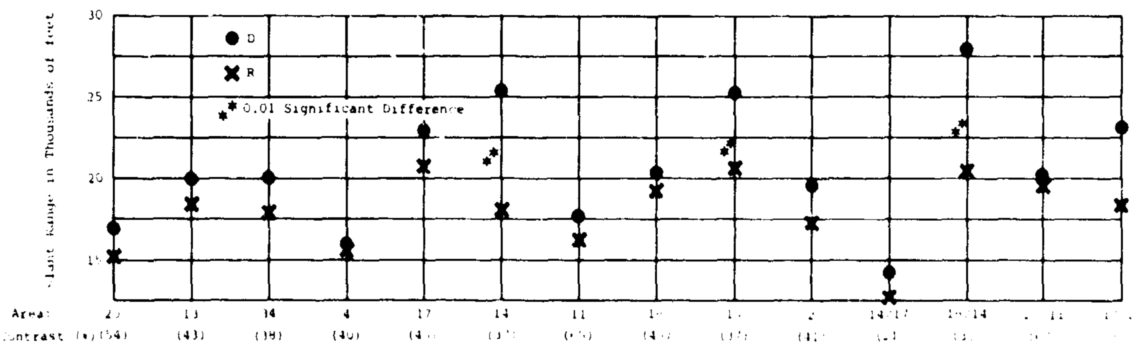


Figure 5. Response by Area Interaction Effect for Study II.

2. Mode

The analysis of variance indicated no significant difference between the color and monochrome presentations (Table VIII). While there was no overall difference in performance because of the color or black and white stimuli, an interaction of mode with target area was significant at the 0.01 level. Figure 6 shows this interaction. Using the t test, three areas elicited significantly different responses as a function of display mode (color or monochrome). Two of these areas (4 and 14) had target and

background areas that were color matched while the third area (14/17) contained a grey target on a dark green background. Areas 4 and 14 elicited better performance for the color presentation while area 14/17 elicited better performance in the monochrome mode. Examination of the individual characteristics of each target area offered only a single clue which was related to performance on area 14/17. While the brightness contrast was 21 percent (within the region where changes in contrast traditionally have had relatively little effect on acquisition performance) it was low compared to that of a large tree which was close by. After the subjects began searching and narrowed down the area, they tended to fixate on the higher contrast spot and then attempt recognition. Many subjects never saw the actual target, although it was within 50 feet (simulated) of the tree. While this accounts for the overall lower performance on this area, it offers no explanation as to why the monochrome presentation resulted in detection at a greater range. There is, likewise, no reasonable explanation for the superior performance on the color presentations of areas 4 and 14. Search was not considered an important factor here because both targets were placed in the middle of open fields toward the front of the terrain model. However, search is suspected of confounding the result (as well as compounding the detection problem) for other target areas.

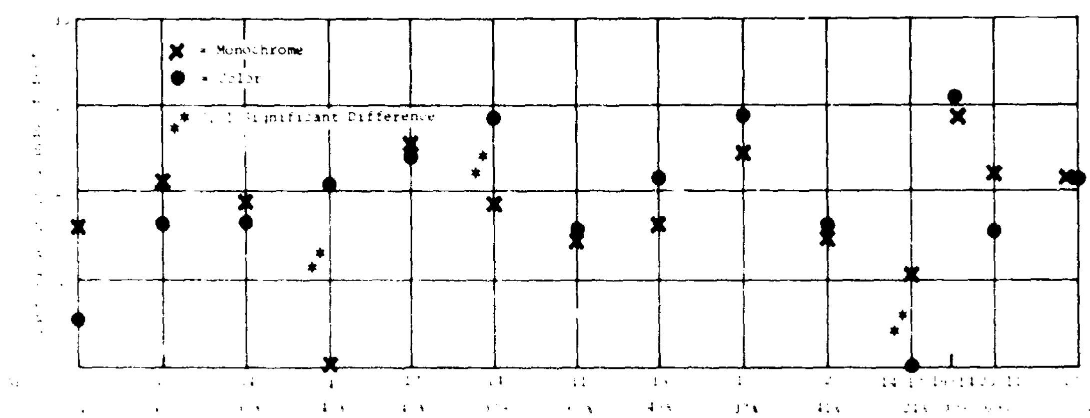


Figure 6. Area by Mode Interaction Effect for Study II.

The general finding was that, at the relatively high contrast values used in this study, the use of a color display does not enhance target acquisition. It is conceivable, however that, at low contrast values, a color presentation could effect detection at a greater slant range than a monochrome presentation. For example if the brightness contrast of a mismatched target/background combination were zero, the target would be visible solely due to the color mismatch (color contrast). For low brightness contrast values, then, the question of color versus monochrome efficacy is still undertermined.

3. Area.

There were performance differences attributable to the differing characteristics of various areas as indicated by the 0.01 level of significance of this factor. Again, for the most part, this appeared to be due to brightness contrast effects and not to the target-to-background color mismatches. The Area by Mode interaction, as discussed earlier, was similar to the Area by Response interaction in that it accounted for a small amount of variance, but with no identifiable causitive factors. Figure 7 shows the detection response at each area for both color and monochrome conditions.

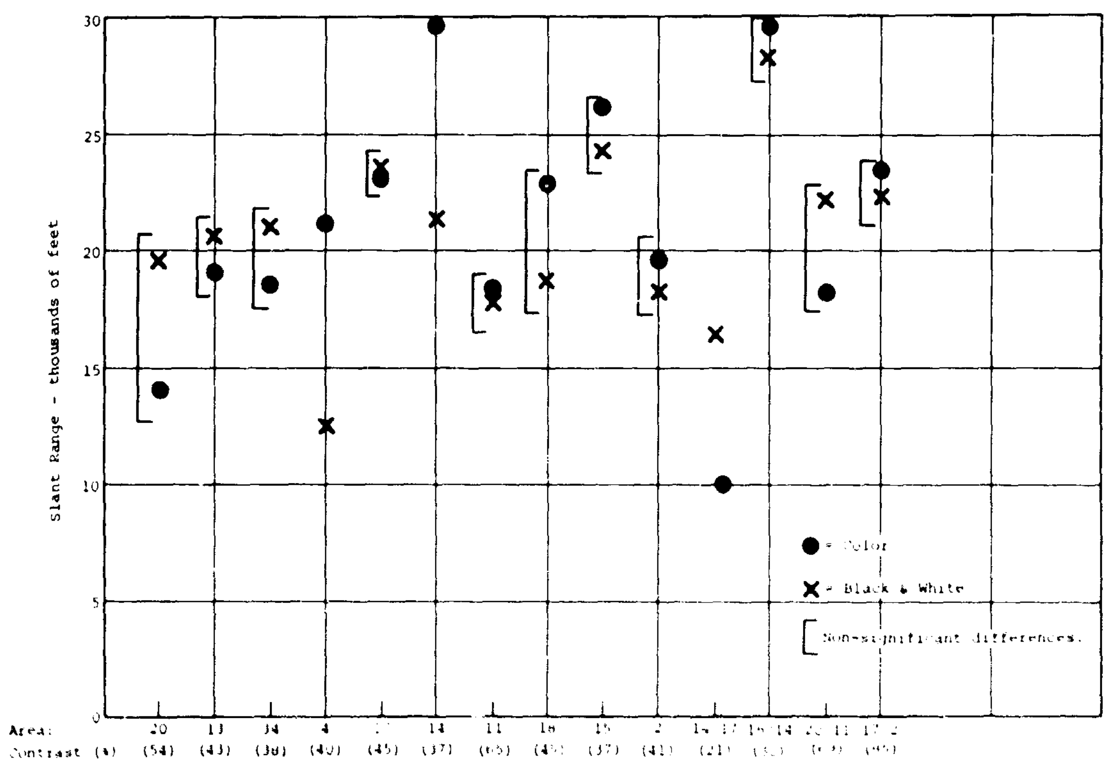


Figure 7. Detection Performance as a Function of Mode for Each Area.

IV. CONCLUSIONS

A. STUDY I - TRANSITIONING TO ON-BOARD DISPLAY

The quality of on-board TV display systems as typified by the equipment used in this study (see Section II) produces a large difference in daytime target acquisition performance between directly viewing a target and viewing it on a monitor. Image magnification up to five times the directly viewed target size is required for equivalent detection via TV. Narrower FOVs could be used to produce greater image magnifications and provide increased TV detection ranges. However, the size of the displayed terrain areas is reduced correspondingly. Thus, accurate, automatic alignment of the TV to the direct visual line-of-sight (LOS) becomes more and more critical. Unless accurate alignment is maintained, when the transition is made, the displayed terrain area may not include the visually acquired target, or the target image may be offset to the degree where available display search time (prior to losing the target image from the FOV) will be unacceptably short. In either case, TV detection performance would be enhanced only at the expense of added sophistication in the direct visual-to-TV alignment method employed.

In this study the task of the pilot was simplified so that he had no other cockpit duties. In single place aircraft, the problem of increased pilot workload is probably the greatest single factor that is countering the effects of improved display systems (Erickson, personal communication). The time required to locate the target on the display following direct visual detection, was 17 to 20 seconds. This time factor, obtained with the smallest FOV represents the best test condition evaluated. Even so, this is an unacceptably long interval for weapon systems which employ the direct vision-to-display transition process for target acquisition prior to weapon delivery. It is projected that this time would be as much as 50 percent longer when the pilot is busy with aircraft duties and/or dodging enemy fire. Target enhancing systems such as spectral signature and infrared have the potential of reducing acquisition times by providing more effective target cuing. The major conclusion remains that, with present display systems, the aircrewman is still restricted in his efforts to detect and recognize targets, i.e., these displays must be considered as part of a weapon system that has to be adapted to and utilized, and not as an aid in the critical task of target acquisition. Substantial improvement in TV display subsystem quality is required to provide acceptable direct-viewed-to-onboard-display transitioning.

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B. STUDY II - COLOR VERSUS MONOCHROME TV DISPLAYS

This exploratory study allowed a comparison of stimulus material which was identical except that the scene was displayed either in color or black and white. The results indicated rather conclusively that color contrast did not affect target acquisition performance for this type of mission over the range of target/background conditions used. Brightness contrast appeared to determine acquisition distance more than any other factor. For the targets which were mismatched, i.e., target color and background colors differed, performance was no different from those target/background areas which differed only in brightness contrast. It should be noted, however, that contrasts on all of the mis-matched target/background combinations used in this study were greater than 20 percent. Apparently, the response effects resulting from this relatively high level of contrast overshadowed the effects associated with color mismatch. At low brightness contrast values it would be expected that color contrast could have an effect. The unavailability of an instrument which can measure small-area color contrast and the limited scope of this study precluded a detailed psychophysical examination of these factors. It is concluded that color contrast normally plays a secondary role in airborne target acquisition. Generally, target/background color mismatch is the dominant cue only in the case where brightness contrast is a low value. In this case, target acquisition performance would be expected to be marginal to unsatisfactory unless other enhancement techniques, e.g., spectral signature or infra red sensing also are incorporated into the system.

APPENDIX

TEST FACILITIES AND EQUIPMENT

A. GUIDANCE DEVELOPMENT CENTER

The flight simulation and video recording operations were performed in the Martin Marietta Guidance Development Center (GDC). This facility includes a Computer laboratory, Radar Guidance Laboratory, and Optical Guidance Laboratory. Figure 8 is a diagram of the GDC layout. The Radar Guidance Laboratory was not used in this study.

The simulation of range closure is accomplished by longitudinal closing of the terrain model. This motion is controlled by the analog computer.

The terrain model used in this simulated target acquisition task is a 40 by 40 foot, three-dimensional target model simulating natural and man-made features of particular military significance. Typical of the many tactical targets provided are the hydroelectric plant, Vietnamese type village, an airport and harbor area with oil dump and train marshalling yard. The terrain simulation includes a wide spectrum of topography including mountains, desert and farming areas, rivers, lakes, residential areas and open, undeveloped land. The target and terrain features have been reproduced at a scale of 600:1 and contain minute detail. Controlled illumination is provided inside the laboratory, but the terrain model may also be moved outdoors to take advantage of natural illumination. The degree of contrast control required in this test necessitated the use of the indoor illumination. Figure 9 shows the terrain model and Figure 10, a typical target and target area.

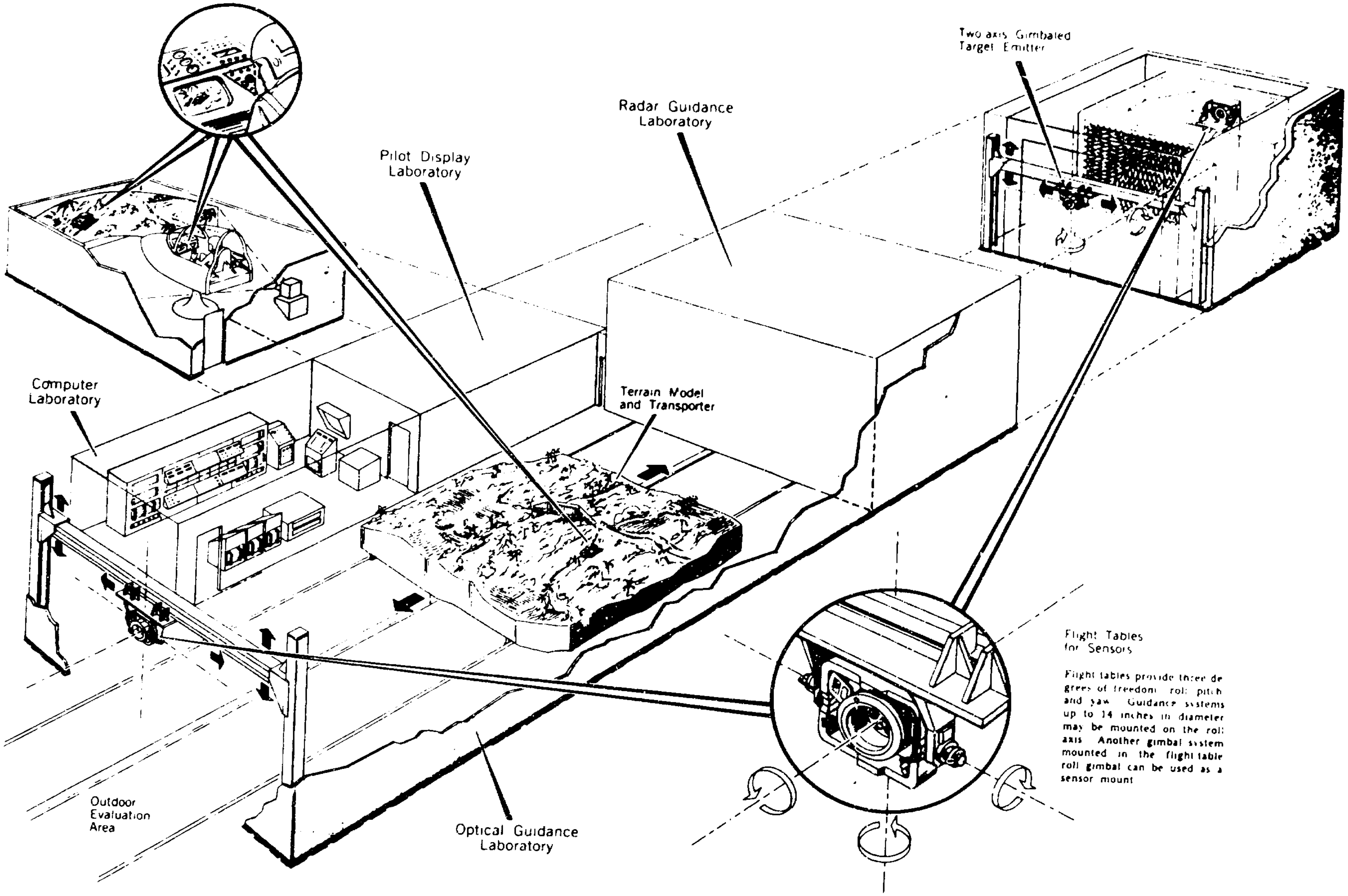

Figure 8. Guidance Development Center (GDC).

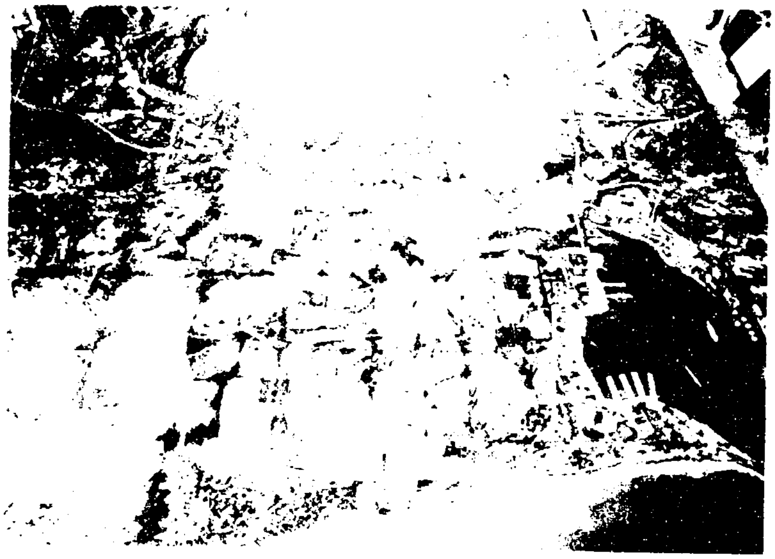

Figure 9. GDC Terrain Model.

Figure 10. Typical Target and Target Area on Terrain Model.

B. TELEVISION SYSTEMS

Study I - The closed circuit TV system used in this study was a commercial grade system operating at a standard 525 line/30 frame rate. The TV camera was a COHU Model 2004-001 which employed a ruggedized high resolution vidicon, type 4503. A Conrac 8-inch diagonal, 3:4 aspect ratio monitor (Model CNB8) having approximately 490 active scanning lines was used to display the target scene. The system provided a nominal horizontal resolution of 500 TV lines and displayed nine shades of grey ($\sqrt{2}$ steps) when viewing a standard resolution chart.

Study II - The color TV system for this study was an IVC TV camera, Model 300A. The video recorder was an IVC Model 825. The display was a SONY Trinitron color monitor, Model CVM 1200UA having a 12-inch diagonal active screen size. This system produced an approximate 300 TV line resolution and displayed nine shades of grey ($\sqrt{2}$ steps) when viewing a standard resolution chart.

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